A Comparison of Rates of Fatal Ejection From Manual and Automatic Belt Cars

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October 1987

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ABSTRACT

Federal Motor Vehicle Safety Standard 208 requires manufacturers to provide automatic restraint systems -- either air bags or automatic belt systems -- for outboard front seat occupants in all new passenger cars by 1990. Concern about occupant ejection in crashes has arisen because of the designs and operation of some types of automatic belts. The purpose of the present study was to examine occupant ejection in comparable manual and automatic belt equipped cars involved in fatal crashes. Fatal crash data were examined for the two-point automatic belt equipped Volkswagen Rabbit and the two-point motorized belt equipped Toyota Cressida, and the experience of these cars was compared, respectively, to that of VW Rabbits and Nissan Maximas equipped with three-point manual belts. (No attempt was made to determine belt use, rather the experience of cars with the two types of belts were compared.) The percentage of front seat fatalities that involved ejection was 18 in the Toyota Cressida and 30 in the Nissan Maxima. The comparable percentages for Volkswagen Rabbits were 18 with automatic belts and 20 with manual belts. Volkswagen Rabbits equipped with the automatic two-point belt system and Toyota Cressidas equipped with the motorized two-point belt system provide occupant protection from ejection in fatal crashes that is, at least, comparable to that of cars equipped with conventional manual three-point belt systems.

Federal Motor Vehicle Safety Standard (FMVSS) 208 requires a phased introduction of automatic restraint systems for front seat occupants. Ten percent of 1987 model year cars must be equipped with either automatic seat belts in both outboard front seat positions or with driver side air bags; this increases to 25 percent in the 1988 model year, 40 percent in the 1989 model year, and all cars in model year 1990 and later. If a car is equipped with a driver side air bag, the right front seat outboard position may have a manual belt until model year 1994, at which time both front seat positions must have automatic restraints.

As the 1990 deadline for full compliance with FMVSS 208 approaches, and the proportion of automatic restraint vehicles that the manufacturers must produce increases, car manufacturers are making decisions on how to fulfill these requirements. Some manufacturers are committed to providing air bags, and others have chosen automatic belt systems of various types. For example, General Motors (GM) uses a three-point automatic belt with upper attachment on the door and the reel mechanism located in the lower door. This design is intended to ensure that the door remains closed when the belt is in use [General Motors, 1986]. Volkswagen uses a two-point automatic belt with upper attachment on the door, the reel mechanism located in the center console on the floor, and a knee bolster. Toyota and Ford use a two-point motorized shoulder belt (with the upper attachment above the door frame), a manual lap belt, and a knee bolster. The relative effectiveness of the two-point and three-point automatic belts in comparison with each other and with manual three-point belt system may differ.

Researchers have documented the overall fatal injury experience of occupants in crashes of VW Rabbits and Toyota Cressidas equipped with two-point automatic belts. This research shows that cars with automatic seat belts have lower fatality rates than comparable cars equipped with manual seat belts. In a study of overall fatality rates for the Nissan Maxima and the Toyota Cressida, the manual belt equipped Maxima had a rate of 12.4 fatalities per 100,000 vehicle years of operation, and the automatic belt equipped Cressida had a lower rate of 9.0 fatalities per 100,000 vehicle years of operation [Nash and Eiseman, 1985]. In a National Highway Traffic Safety Administration (NHTSA) study of overall fatality rates for both automatic and manual belt equipped VW Rabbits, the fatality rate for cars with automatic belts was lower than that of cars with manual belts; these were 18.2 fatalities per 100,000 vehicle years of operation compared to 22.6 fatalities per 100,000 vehicle years of operation, respectively [Chi and Reinfurt, 1981]. In addition to lower fatality rates in automatic belt cars, the frequency of insurance injury claims is lower for automatic belt cars than for manual belt cars [HLDI, 1986].

Although previous research has addressed the overall issue of injuries and fatalities in automatic belt cars compared to manual belt cars, little has been done that addresses the specific issue of ejection in cars with two-point automatic belts. Containment of the occupant within the vehicle is a function of the crash performance of the vehicle structure, particularly such components as door locks and windshields. An effective restraint system should, however, be capable of containing the occupant within the vehicle even when one of these components fails.

Containment of occupants in vehicles is extremely important in preventing serious and fatal injuries; occupants who are ejected are four times more likely to die than occupants who are not ejected [Sikora, 1986]. It has been conjectured that two-point automatic belts may not contain the occupant as well in a crash as conventional, manual three-point belt systems. If this conjecture is correct it would mean that the increased belt use of automatic two-point belts was being achieved at the cost of poorer performance. Campbell and Welbourne [1981] suggested that, if there is no lap belt worn, the two-point automatic belt may be somewhat less effective than a conventional seat-belt assembly in preventing ejection. They stated: "The reduced effectiveness is compounded by the association between door opening and the retraction of the belt from the occupant. In the case of the door-mounted belt the consequence is inevitable, but in powered systems retraction may be inhibited in the event of accidental door opening" [Campbell and Welbourne, 1981].

The purpose of the present study was to examine the actual experience of occupant ejection in manual and automatic two-point belt equipped cars in crashes. The experience of vehicles with two different types of automatic belts was examined: the door-mounted, nonmotorized automatic belt system used in the Volkswagen Rabbit and the door-frame-mounted motorized belt system used in the Toyota Cressida. These belt systems represent the two main design philosophies currently used for two-point automatic belts, and the experience of these cars can provide information about the potential problem of occupant ejection with two-point belts. The principal purpose of automatic belt systems is to increase usage without compromising crash protection. It should be noted that automatic belts are required to be dynamically tested whereas manual belt systems currently are not (49 CFR 571.208). Also, these cars were selected because they have been marketed for a sufficiently long period that their crash samples were large enough for analysis and similar cars with manual belts were available for comparison. The Nissan Maxima, which has manual belts, is comparable in size and weight to the Toyota Cressida. Different models of the Volkswagen Rabbit were equipped with automatic or manual belts; thus Rabbits with manual belts provide a comparison group for Rabbits with automatic belts.

Description of Belt Systems

The Volkswagen Rabbit belt system consists of a two-point shoulder belt that moves into position when the door is closed and a padded knee bolster in the lower section of the dashboard. The belt stretches across the occupant from the outboard shoulder to the inboard hip. The belt is attached to the top of the door above and to the rear of the shoulder, and it is anchored at the hip by a retracting device secured on the seat frame. An emergency release on the door connection allows the belt to be detached. Because the Rabbit system does not have a lap belt, the knee bolster is designed to cushion the knees and limit the forward movement of the lower body; it absorbs the foward force of the pelvis through the knee-thigh-hip complex. The sheet metal seat frame also prevents the lower body from sinking excessively into the seat and modifying the kinematics of the upper torso [Volkswagen of America, 1985].

The Toyota Cressida automatic belt system consists of a motorized two-point shoulder belt, a knee bolster, and a manual lap belt. Unlike a fixed point automatic belt system, such as in the Rabbit, the upper end of the two-point shoulder belt moves along a guide rail above the front door frame; it moves forward and out of the way of entry and exit when the door opens, and it moves back into place at the rear end of the track when the door closes. The retractor is located in a center console between the two front seats. In addition to the emergency locking retractor assembly, there is a gravity sensor emergency lock on the motorized guide rail. In the event of a door opening during a crash, the shoulder belt is prevented from tracking forward by a pin in the guide rail. For lower body restraint, the Cressida has a manual lap belt and a knee bolster [Toyota Motor Sales U.S.A., 1981]. This system is designed so that the motorized shoulder belt used in combination with the manual lap belt will effectively prevent ejection in a crash.

The manual belt systems in both the Nissan Maxima and the Volkswagen Rabbit are conventional three-point combination lap and shoulder belts. This system has two anchor points on the floor on the outboard side; the lap portion of the webbing extends from the foward floor anchor across the occupant, while the shoulder portion of the webbing extends up from the rear floor anchor, over the shoulder, and then across the occupant's torso joining the lap portion in one buckle.

METHODS

To compare actual ejection experiences of fatally injured front outboard occupants of automatic belt system cars with those in manual belt system cars, Fatal Accident Reporting System (FARS) data from 1981-1985 were used [U.S. DOT, 1981-85]. Because the research question addressed is what are the ejection rates given that a car is equipped with manual or passive belts, control for belt use was not attempted in this analysis. That is, the overall efficacy of the belt system as used rather than its effectiveness given that a belt was worn was examined. The two comparison populations were the Toyota Cressida versus the Nissan Maxima, and the VW Rabbit automatic belt model versus the manual belt model. The model years 1981-85 were selected because 1981 was the earliest model year for Cressidas with automatic belts. Also, 1981 was the first year automatic and manual belt Rabbits could be identified from the vehicle identification number.

All 1981-85 Volkswagen Rabbits involved in fatal crashes in which a front outboard occupant was killed were selected as cases from the FARS data for the years 1981 through 1985. The VIN was used to determine whether the Rabbits were automatic or manual belt models. Since the 1981 model year, all Cressidas have been equipped with a motorized belt system, and all Maximas have been equipped with a three-point manual belt system. The total number of left and right front seat fatalities and the number of those fatalities associated with ejection were counted for each of the comparison populations. Ejection refers to a person completely or partially thrown from the passenger compartment of the vehicle in the course of a crash.

To interpret and explain the ejection results, sample comparability must be examined. If the sample variations in the two car populations within each comparison group are not significant, then nearly all the ejection difference can be attributed to the difference in the restraint systems. To assess the similarity of the sample populations, the following factors were compared: the mix of single vehicle and multivehicle crashes, the proportion of rollovers, the proportion of crashes in speed zones less than 35 miles per hour and more than 35 miles per hour, the proportion of crashes on rural roads and urban roads, the points of impact of the crashes, the ages of the drivers, and the ages of the fatalities. The Toyota/Nissan population are not necessarily comparable to the VW Rabbit automatic/manual population, but the intent here is not to compare across these two populations.

RESULTS

There were no significant differences for the crash factors analyzed within the Toyota Cressida and Nissan Maxima populations; that is, they are comparable beyond just the cars themselves (Table 1). The VW Rabbit automatic belt population is comparable to the VW Rabbit manual belt population with one exception. There were significantly more single vehicle crashes and rollover crashes among the manual belt Rabbits than among the passive belt Rabbits. Although these two crash factors were analyzed separately, most of the rollover crashes were also single vehicle crashes.

The percentage of fatalities involving ejection for the comparable cars with different belt systems are shown in Table 2. In both comparisons, the cars with automatic belts have lower ejection rates than the comparable cars with manual belts.

The Nissan Maxima ejection percentage of 30 appeared unusually high relative to the other percentages found in this study. To establish whether this ejection rate was an outlier, additional ejection percentages for several similar cars with three-point manual belt systems were calculated from the FARS data. These percentages with ejection were: Volvo 240, 33; Audi 5000, 29; Peugeot 505, 20; and Saab 900, 43. Thus, the Maxima rate appears to be comparable with these similarly sized cars, and the Cressida ejection percentage appears to be low.

The proportion of ejected occupants is nearly equal for both Rabbit belt systems. The slightly higher ejection rate in the manual belt Rabbits may be partially attributed to the higher number of single vehicle rollover crashes in these Rabbits.

In order to compare the ejection rates, the data are analyzed in a 2 X 2 contingency table:

	Fatality with Ejection	Fatality Without Ejection	
Automatic Belt Rabbit	17	79	96
Manual Belt Rabbit	38	155	193
	55	234	289

If the null hypothesis is that the number of fatal ejections is independent of the belt system, then using the Fisher's Exact test, a p-value much greater than 0.05 ($p = 0.80$) is calculated and the null hypothesis is accepted. The odds ratio (OR) for the odds of ejection, given an occupant is in an automatic belt car, is 0.88, or slightly less than one. This odds ratio, however, is not statistically significant (95 percent confidence limits: OR = 0.44 to 1.72).

The proportion of ejected occupants in the automatic belt Toyota Cressida and the manual belt Nissan Maxima is clearly different for the two belt systems. The data are analyzed in a 2 X 2 contingency table:

	Ejected	Not Ejected	
Toyota Motorized Belt System	10	46	56
Nissan Manual Belt System	24	56	80
	34	102	136

Assume the null hypothesis to be that the number of fatal ejections is independent of the belt system. Using the Fisher's Exact test again, a p-value of 0.08 is calculated. Although the null hypothesis is accepted at the 5 percent significance level, the number of ejections from the automatic belt Cressida is substantially lower than the Maxima. The ratio for the odds of ejection, given an occupant is in the automatic belt car, is 0.51. Again, the odds ratio is not statistically significant (95 percent confidence limits: OR = .20 to 1.2), but this result shows that there appears to be a protective effect from the automatic belt.

DISCUSSION

In summary, this analysis of FARS data has shown that the proportion of fatalities involving ejection is lower in automatic belt equipped cars than similar manual belt equipped cars. This may be related in part to differences in belt usage; reliable information on belt use of fatally injured occupants in these cars is not available from FARS. However, shoulder belt use rates in the Toyota Cressida in noncrash populations are estimated at about four and a half times those in the Nissan Maxima, and in the automatic belt Rabbit, they are about three times those in the manual belt Rabbits [Perkins, Cynecki, and Goryl, 1983]. In addition, Toyota occupants have the option of using a manual lap belt that is designed to assist in preventing ejection. Because the FARS recording of belt use is unreliable, the question of whether the two-point automatic belt system is more likely to result in ejection than a manaul lap/shoulder belt when both systems are in use could not be addressed in this study.

The automatic two-point belt and knee bolster system in the VW Rabbit and the motorized two-point belt, manual lap belt, and knee bolster system in the Toyota Cressida provide at least comparable, if not better, occupant containment than conventional manual three-point belt systems with their current level of use. Occupants in cars with two-point automatic belts are not at greater risk of fatality from ejection.

ACKNOWLEDGEMENT

The author greatly acknowledges the following people from the Institute for their invaluable support: Maria Penny; Jackson Wong; Ian Jones; Sharon Rasmussen; Karen Barnes; and Susan Dussinger.

Table 1
Comparison of Crash Factors for
Automatic Belt and Manual Belt Cars

Crash Factor	Toyota Cressida: Automatic Belt (49 Crashes)		Nissan Maxima: Manual Belt (76 Crashes)		P-Value (χ^2)
	Number	Percent	Number	Percent	
Crash Type					
Single Vehicle	22	45	33	43	p > 0.05
Multivehicle	27	55	43	57	
Point of Impact					
Front	25	51	25	33	p > 0.05
Side	8	16	22	29	
Rear	0	0	0	0	
Unknown	16	33	29	38	
Rollover					
Yes	11	22	20	26	p > 0.05
No	38	78	56	74	
Posted Speed					
≤ 35 mph	6	12	11	15	p > 0.05
> 35 mph	42	86	65	85	
Unknown	1	2	0	0	
Road Type					
Urban	23	47	32	42	p > 0.05
Rural	25	51	44	58	
Unknown	1	2	0	0	
Age of Driver (Yrs)					
0 - 15	0	0	0	0	p > 0.05
16 - 24	10	21	15	20	
25 - 34	11	22	28	37	
35 - 44	5	10	7	9	
45 - 54	4	9	8	11	
55 - 64	8	16	6	8	
≥ 65	11	22	12	15	
Age of Fatality					
0 - 15	0	0	1	1	p > 0.05
16 - 24	13	23	16	20	
25 - 34	11	20	31	38	
35 - 44	5	9	4	5	
45 - 54	2	4	6	8	
55 - 64	9	16	6	8	
≥ 65	16	28	16	20	

Note: No significant differences at the 5 percent level.

Table 1 (Continued)

Crash Factor	VW Rabbit				P-Value (χ^2)
	Automatic Belt (93 Crashes)		Manual Belt (175 Crashes)		
	Number	Percent	Number	Percent	
Crash Type					
Single Vehicle	22	24	70	40	$p < 0.05$*
Multivehicle	71	76	105	60	
Point of Impact					
Front	49	53	65	37	$p > 0.05$
Side	21	23	47	27	
Rear	3	3	4	2	
Unknown	20	21	59	34	
Rollover					
Yes	13	14	46	26	$p < 0.05$*
No	80	86	129	74	
Posted Speed					
$\leq$ 35 mph	3	3	18	10	$p > 0.05$
> 35 mph	85	92	152	87	
Unknown	5	5	5	3	
Road Type					
Urban	30	32	65	37	$p > 0.05$
Rural	62	67	109	62	
Unknown	1	1	1	1	
Age of Driver (Yrs)					
0 - 15	0	0	0	0	$p > 0.05$
16 - 24	28	30	67	38	
25 - 34	24	26	44	25	
35 - 44	20	21	24	14	
45 - 54	7	8	16	9	
55 - 64	9	10	14	8	
$\geq$ 65	5	5	10	6	
Age of Fatality					
0 - 15	3	3	5	3	$p > 0.05$
16 - 24	26	27	76	39	
25 - 34	22	23	43	22	
35 - 44	21	22	24	12	
45 - 54	9	10	17	9	
55 - 64	8	8	9	10	
$\geq$ 65	7	7	10	5	

* Significantly different at the 5 percent level.

Table 2
Proportion of Fatally Injured Front Seat Occupants
Who Were Ejected from Cars With Automatic and Manual Belt Systems

Car	Belt System	Number of Fatalities	Number of Ejections	Proportion Ejected
VW Rabbit	Automatic	96	17	0.18
VW Rabbit	Manual	193	38	0.20
Toyota Cressida	Automatic	56	10	0.18
Nissan Maxima	Manual	80	24	0.30

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